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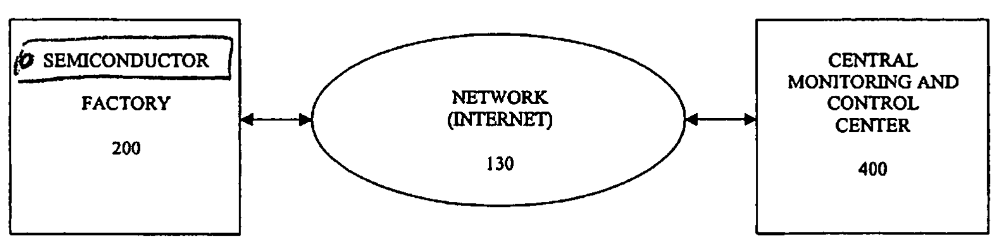
(54) Title: METHOD AND APPARATUS FOR MONITORING CONTROL AND ANALYSIS OF INDEPENDENT SYSTEMS IN A MANUFACTURING FACILITY



(57) Abstract: A method and apparatus are provided for remotely configuring, operating and monitoring equipment in a manufacturing facility. An interface is provided that allows a remote user to establish a connection with desired equipment in order to configure, operate or monitor the equipment. The disclosed interface performs any required translation between the diverse equipment and protocols of different equipment manufacturers. A web-based connection to remote equipment allows a variety of diverse equipment systems to be accessed and controlled in a uniform manner. Historical data can be analyzed following a failure using pattern recognition techniques to identify data patterns that suggest an imminent failure. The remote monitoring of ancillary equipment from a number of vendors in a semiconductor factory allows a multipoint failure to be analyzed and a root cause to be identified.

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METHOD AND APPARATUS FOR MONITORING, CONTROL AND ANALYSIS OF INDEPENDENT SYSTEMS IN A MANUFACTURING FACILITY

Cross Reference to Related Applications

This application claims the benefit of United States Provisional Application Number 60/337,821, filed November 5, 2001, incorporated by reference herein.

Technical Field

The present invention relates generally to the monitoring and control of equipment, and more particularly, to methods and apparatus for the remote configuration, operation and monitoring of equipment within a factory, such as a semiconductor factory.

Background Art

A manufacturer typically coordinates a number of operational stages in order to manufacture and deliver finished goods to a customer. The manufacture of semiconductor circuits, for example, typically involves a variety of component devices, often referred to as ancillary equipment, such as pumps, delivery systems and abatement equipment, that are generally provided by a number of different vendors. The delivery systems, for example, deliver or remove various materials, such as solids, liquids and gases, to or from various process tools that perform specific steps in the manufacture of semiconductor circuits.

The monitoring of component devices in a semiconductor factory is important, since the failure of any one of these component devices that are used in the fabrication process could easily suspend operations of a much larger unit or even the entire semiconductor factory. Since the cost of lost productivity has been estimated to vary from $10,000.00 to $250,000.00 per hour, the vendors of the components used in the fabrication process do not want to be responsible for suspending the operation of the semiconductor factory.

When a component used in the fabrication process fails, a service representative of the semiconductor factory must initially diagnose the cause of the failure to identify the vendor of the particular failing component. The diagnosis is often difficult when there are a number of interrelated ancillary devices feeding a process tool. There may be a number of contributing events that cause a given failure. Once a single ancillary

device has been identified, the corresponding vendor typically sends a field service representative to the semiconductor factory to diagnose and remedy the particular problem. Once the field service representative arrives at the semiconductor factory, the field service representative performs a more detailed diagnostic procedure on the failing component to identify the actual source of the problem. Frequently, the field service representative must order replacement parts that are required before the problem can be remedied. Thus, even when replacement parts are in stock, a failure can easily cause a semiconductor factory or a portion thereof to be down for two business days.

The semiconductor industry has recognized the need for centralized monitoring of a semiconductor factory, and the ability to provide remote failure detection and diagnostics. International Sematech, a consortium of semiconductor industry companies, has published a specification that provides guidelines and requirements for implementing an e-Diagnostics system within a semiconductor factory. *See*, International Sematech, e-Diagnostics Guidebook, Version 1.4, September 3, 2002, incorporated by reference herein. The suggested capabilities are designed to be broadly based on open standards, compatible with existing structures, and subject to evolving technology. *

International Sematech has specified four levels of e-diagnostic capabilities for an e-Diagnostics system. Level 0, referred to as "Access and Remote Collaboration," requires remote connectivity to a tool and remote collaboration capabilities between a tool in the factory and remote field service experts. Level 1, referred to as "Collection and Control," requires remote configuration, operation and monitoring of equipment, as well as the collection and storage of data in real time. Level 2, referred to as "Analysis," requires automated reporting and analysis with statistical process control (SPC) capabilities. Finally, Level 3, referred to as "Prediction," requires predictive maintenance, self diagnostics and automated notification. Equipment that is specified by a supplier to be compliant with a given level must include all lower level capabilities as well.

In order to enable the remote configuration, operation and monitoring of Level 1 equipment, as well as the collection and storage of data from Level 1 equipment in real time, a need exists for an interface that permits a remote computing system to communicate with Level 1 equipment over a network. A further need exists for an interface that permits a remote computing system to communicate with Level 1 equipment provided by a third party vendor over a network. The interface should enable bi-

directional communication between a remote authorized field service representative and equipment in a semiconductor factory by means of a network or modem connection to thereby permit interactive configuration, operation and monitoring.

Preferably, an imminent failure is detected and avoided before the failure even occurs. In this manner, vendors can improve the reliability of their equipment, decrease equipment down time and thereby increase the confidence of their customer (the semiconductor factory). In addition, the vendor can reduce the time and expense associated with sending field service representatives to the semiconductor factory. Even when it is necessary to send a field service representative to the semiconductor factory to perform a preventative maintenance task, the amount of required time is generally significantly lower than a service call requiring a fault diagnosis and repair. In order to enable the preventative maintenance of Level 3 equipment, a need exists for automated algorithms that predict a failure before it occurs. A further need exists for a root cause analysis tool that can mine data associated with a failed device and other contributory factors and identify patterns in the data the suggest a failure is about to occur.

Summary of the Invention

Generally, a method and apparatus are disclosed for remotely configuring, operating and monitoring equipment in a semiconductor factory or another manufacturing facility. In addition, data from such equipment is collected and stored for subsequent analysis. According to one aspect of the invention, an interface to equipment in a semiconductor factory is provided that allows a remote user to establish a connection with the equipment in order to configure, operate or monitor the equipment. The disclosed interface allows a remote connection to be established with existing (legacy) and third party equipment that has been retrofitted with the interface. In addition, the interface performs any required translation between the diverse equipment and protocols of different equipment manufacturers.

A web-based connection to remote equipment in a semiconductor factory allows a variety of diverse equipment systems to be accessed and controlled in a uniform manner over a network connection. In this manner, a central monitoring and control center provides a centralized collection point for equipment data, and permits decentralized distribution of personnel.

According to another aspect of the invention, the historical data that is collected from equipment in a semiconductor factory can be analyzed following a failure using pattern recognition techniques to identify patterns in the data that suggest a failure is about to occur. Once a pattern is identified, a rule can be generated defining the pattern in terms of one or more predefined data characteristics. Thereafter, real-time data can be monitored to detect the predefined data characteristic(s) and thereby indicate or predict when a failure is about to occur.

The remote monitoring of ancillary equipment from a number of vendors in a semiconductor factory and the collection and storage of data from such ancillary equipment also allows a multipoint failure to be analyzed and a root cause to be identified. The present invention facilitates a diagnosis when there are a number of interrelated ancillary devices feeding a single process tool in a semiconductor factory. A number of contributing events may cause a given failure and the present invention allows all such contributing events to be identified and evaluated as the root cause event.

A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference to the following detailed description and drawings.

Brief Description of the Drawings

FIG. 1 illustrates the network environment in which the present invention operates;

FIG. 2 is a schematic block diagram of a portion of a local area network with a semiconductor factory in accordance with the present invention;

FIG. 3 illustrates the monitoring and control of various equipment devices in a semiconductor factory in accordance with the present invention;

FIG. 4 is a schematic block diagram of a central monitoring and control center incorporating features of the present invention;

FIG. 5 is a flow chart describing a data collection process incorporating features of the present invention;

FIG. 6 is a flow chart describing a preventative maintenance learning process incorporating features of the present invention; and

FIG. 7 is a schematic block diagram of an exemplary air composition monitor incorporating features of the present invention.

Detailed Description

FIG. 1 illustrates a network environment in which the present invention can operate. As shown in FIG. 1, a semiconductor factory 200, discussed below in conjunction with FIGS. 2 and 3, is connected over a network 130, such as the Internet or Public Switched Telephone Network, to a central monitoring and control center 400, discussed below in conjunction with FIG. 4. The semiconductor factory 200 may include one or more local area networks employing well-known manufacturing equipment system (MES) connectivity techniques to connect the various equipment devices within the semiconductor factory 200. While the present invention is described in an exemplary semiconductor factory, the present invention can be applied to any manufacturing facility where multiple systems are collecting data, as would be apparent to a person of ordinary skill in the art.

The present invention enables the remote configuration, operation and monitoring of equipment in a semiconductor factory, as well as the collection and storage of data from such equipment in real time. The present invention provides an interface to equipment in a semiconductor factory that allows a remote user to establish a connection with the equipment in order to configure, operate or monitor the equipment. According to one aspect of the invention, the interface allows a remote connection to be established with existing and third party equipment. In addition, the interface performs any required translation between the diverse equipment of different equipment manufacturers, each potentially having unique signal formats, protocols and data types. In this manner, the interface enables bi-directional communication between a remote authorized field service representative and the equipment in a semiconductor factory by means of a network or modem connection.

According to another aspect of the invention, the historical data that is collected from equipment in a semiconductor factory is analyzed following a failure using pattern recognition techniques to identify patterns in the data that suggested a failure was about to occur. Once a pattern has been identified, a rule is generated defining the pattern in terms of one or more predefined data characteristics. Thereafter, real-time data can be

monitored to detect the predefined data characteristic(s) and thereby indicate or predict when a failure is about to occur.

The remote monitoring of ancillary equipment from a number of vendors in a semiconductor factory and the collection and storage of data from such ancillary equipment allows a multipoint failure to be analyzed and a root cause to be identified. The present invention facilitates a diagnosis when there are a number of interrelated ancillary devices feeding a single process tool in a semiconductor factory 200. There may be a number of contributing events that cause a given failure and the present invention allows all such contributing events to be identified and evaluated as the root cause event.

With the web-based application or user interface of the present invention, access to and control of a variety of diverse equipment systems is obtained via network connections. In this manner, the central monitoring and control center 400 provides a centralized collection point for equipment data, and permits decentralized distribution of personnel.

FIG. 2 illustrates a local area network that may be employed in the semiconductor factory 200 to connect one or more equipment devices within the semiconductor factory 200. The local area network may comprise an Ethernet, dedicated phone line, wireless modem, optical network, or any such communication pathway as known to those skilled in the art. As shown in FIG. 2, a process tool 210 or related ancillary equipment (or both) is connected to one or more programmable logic controllers (PLCs) 220 that control the operation of the process tool 210 and related ancillary equipment. The process tool 210 or related ancillary equipment may be embodied as any component device within a semiconductor factory 200 that processes, measures, tests, or packages semiconductor material, such as tools, sensors, delivery and abatement systems, and control systems. The process tool 210 and programmable logic controller 220 generate data signals that are supplied to one or more network interface cards (NICs) 230. The network interface cards 230 operate to query individual programmable logic controllers 220 for user-defined parameters. This data may be stored by the network interface card 230 or immediately forwarded over the network 130 to the central monitoring and control center 400.

According to one aspect of the invention, the network interface cards 230 use automated electronic transfer of data to perform information exchange with the local

tools 210 (and related ancillary equipment) and the central monitoring and control center 400. The network interface cards 230 must translate between the diverse equipment of a number of manufacturers, each potentially having unique signal formats and protocols as well as different databases and data types. The network interface cards 230 include translators that translate the raw signals and data from a given process tool 210 into a desired uniform format. In one embodiment, a network interface card 230 includes a driver that performs the translation between the format of a given tool manufacturer and a desired uniform format. The translated raw data can then be loaded into an application server by the central monitoring and control center 400 for further processing.

In one embodiment, the network interface card 230 incorporates the features and functions to enable the remote configuration, operation and monitoring of Level 1 equipment, as specified by International Sematech, as well as the collection and storage of data from Level 1 equipment in real time.

The present invention thus allows monitoring or integration (or both) of independent but related equipment systems and data sources within a semiconductor factory 200. The network interface cards 230 permit the central monitoring and control center 400 to gather raw data from diverse data sources. These data sources may comprise databases in which data is stored or equipment systems from which the data is gathered. Software code executed within the network interface card 230 translates data received from the programmable logic controller 220 associated with the data source into the desired uniform format.

In addition, the network interface card 230 for a given tool 210 may include one or more sensors for monitoring the operation of the tool 210, if the tool 210 does not provide this functionality itself. In addition, as discussed below in conjunction with FIG. 7, a network interface card 230 may be associated with one or more gas sensors that monitor the gas levels in a cabinet or in other locations of a semiconductor factory 200 for harmful conditions.

The network interface card 230 preferably secures the data that is collected from the tools 210 using encryption and access control techniques, in a known manner. In addition, the network interface card 230 is preferably configured to be able to communicate with the central monitoring and control center 400 or another authorized remote device through the firewall of the semiconductor factory 200, using known

techniques. A firewall restricts access between a protected network and external devices by selectively allowing or blocking network traffic based on the content of the packets.

As shown in FIG. 2, the local area network in a semiconductor factory 200 optionally includes a server 240 for interconnecting the various programmable logic controllers 220 and network interface cards 230 associated with each process tool 210. The optional server 240 stores data and provides a central hub for communicating with the central monitoring and control center 400 over the network 130. Alternatively, each network interface card 230 can directly act as a network server for the stored data. In this embodiment, each network interface card 230 would be separately addressable on the network 130, for example, by an IP address.

In addition, each network interface card 230 would include software instructions to generate HTML or other like documents that are populated with the formatted data. By utilizing an HTML screen format and having a unique address, the network interface card 230 becomes a host site, allowing multiple users, including remote field service engineers, to connect to the device, for example, to check on performance, perform upgrades remotely, and diagnose or walk through a problem with a product specialist. A remote user can connect to a desired device, for example, using a uniform resource locator (URL) that describes the address of the device on the network 130.

The network interface card 230 thus allows any authorized user with access to the network to view and/or manipulate any or all of the data and controls of the process tool 210 and their related delivery and removal systems through a common but configurable user interface. For example, an equipment engineer for a set of chemical vapor deposition (CVD) tools may desire to simultaneously view the operations of a bulk delivery system, liquid bulk delivery system, exhaust abatement systems, and other related facility systems. Furthermore, the user interface can be configured to allow the equipment engineer to view real time or historical data, perform statistical analysis, and execute control functions based on this data.

In addition, the network interface card 230 allows diagnostics to be performed remotely by expert field service engineers. This enables field service engineers to quickly identify problems arising within integrated equipment sets without the need for an onsite visit. Furthermore, historical data related to the integrated equipment sets can be

easily created and analyzed without the need for time consuming and manually intensive parsing of diverse data sets.

As shown in FIG. 2, the network interface card 230 includes at least two communication ports, with a first communication port connected to the programmable logic controller 220 and a second communication port coupled to the server 240, or directly to the network 130. The network interface card 230 includes a data monitoring application in order to (i) obtain the raw data from the process tool 210 (via the programmable logic controller 220); (ii) format the raw data in a desired uniform format; and (iii) provide the formatted data to the central monitoring and control center 400.

FIG. 3 illustrates the monitoring and control of various equipment devices in the semiconductor factory of FIG. 2 in accordance with the present invention. In particular, FIG. 3 illustrates how the network interface cards 230, discussed above in conjunction with FIG. 2, allow a remote connection to be established with existing (legacy) and third party equipment. As shown in FIG. 3, new equipment 310 that is enabled with the monitoring capabilities of the present invention can directly store its data in a data storage device 350. Generally, such monitoring-enabled equipment 310 includes the features and functions of the network interface card 230, as discussed above, and would be classified as Level 1 equipment under the Sematech specification.

For those devices that are not enabled with the monitoring capabilities of the present invention, such as legacy devices 320 and devices 330 manufactured by third parties, a network interface card 230 is provided to (i) obtain the raw data from the equipment 320, 330 (e.g., via a programmable logic controller 220, not shown in FIG. 3); (ii) format the raw data in a desired uniform format; and (iii) provide the formatted data to the data storage device 350. The legacy devices 320 and third party devices 330 would be classified as Level 1 equipment under the Sematech specification, only when enabled with the network interface card 230.

In the embodiment shown in FIG. 3, the data storage device 350 is local to the semiconductor factory 200 and is managed, for example, by a chemical management interface 300. The chemical management interface 300 includes a set of data storage and transfer functions 360 that receive the formatted data from the network interface cards 230 and store the data in the data storage device 350. In addition, the data storage and transfer functions 360 coordinate the transfer of data from the data storage device 350 to the

central monitoring and control center 400 for further processing and analysis. In further variations, the data storage device 350 can be part of the server 240 (FIG. 2) or the data can be immediately forwarded to the central monitoring and control center 400 for processing.

FIG. 4 is a block diagram illustrating an exemplary central monitoring and control center 400. As shown in FIG. 4, the central monitoring and control center 400 comprises a computer system 410 that optionally interacts with a Digital Versatile Disk (DVD) 450. Computer system 410 comprises a processor 420, a network interface 425, a wireless network interface 427, a memory 430, a media interface 435, and an optional display 440. Network interface 425 allows computer system 410 to connect to network 130, wireless network interface 427 allows computer system 410 to connect to a wireless network (not shown), while media interfaces 435 allows computer system 410 to interact with media such as a hard drive or DVD 450.

As is known in the art, the methods and apparatus discussed herein may be distributed as an article of manufacture that itself comprises a computer-readable medium having computer-readable code means embodied thereon. The computer-readable program code means is operable, in conjunction with a computer system such as computer system 410, to carry out all or some of the steps to perform the methods or create the apparatuses discussed herein. The computer-readable medium may be a recordable medium (e.g., floppy disks, hard drives, optical disks such as DVD 450, or memory cards) or may be a transmission medium (e.g., a network comprising fiber-optics, the world-wide web, cables, or a wireless channel using time-division multiple access, code-division multiple access, or other radio-frequency channel). Any medium known or developed that can store information suitable for use with a computer system may be used. The computer-readable code means is any mechanism for allowing a computer to read instructions and data, such as magnetic variations on a magnetic medium or height variations on the surface of a compact disk, such as DVD 450.

Memory 430 configures the processor 420 to implement the methods, steps, and functions disclosed herein. The memory 430 could be distributed or local and the processor 420 could be distributed or singular. The memory 430 could be implemented as an electrical, magnetic or optical memory, or any combination of these or other types of storage devices. Moreover, the term "memory" should be construed broadly enough to

encompass any information able to be read from or written to an address in the addressable space accessed by processor 410. With this definition, information on a network, accessible through network interface 425 or 427, is still within memory 430 because the processor 420 can retrieve the information from the network. It should be noted that each distributed processor that makes up processor 420 generally contains its own addressable memory space. It should also be noted that some or all of computer system 410 could be incorporated into an application-specific or general-use integrated circuit.

Optional video display 440 is any type of video display suitable for interacting with a human user of system 400. Generally, video display 440 is a computer monitor or other similar video display. As discussed further below in conjunction with FIGS. 5 and 6, the central monitoring and control center 400 performs a data collection process 500 and a preventative maintenance learning process 600. Generally, the data collection process 500 coordinates the collection of data from one or more semiconductor factories 200. The preventative maintenance learning process 600 analyzes data that is collected from equipment in a semiconductor factory following a failure using pattern recognition techniques to identify patterns in the data that suggested a failure was about to occur and thereafter generate a rule defining the pattern in terms of one or more predefined data characteristics.

FIG. 5 is a flow chart describing an exemplary implementation of the data collection process 500 incorporating features of the present invention. As shown in FIG. 5, the data collection process 500 is initiated during step 510 upon the receipt of formatted data from a network interface card 230. As previously indicated, the network interface cards 230 will translate raw data into a desired uniform format. Alternatively, the network interface cards 230 can just forward the raw data to the central monitoring and control center 400 for translation and further processing. In addition, the extraction of relationship information may be performed by either the distributed network interface cards 230 or the central monitoring and control center 400.

As shown in FIG. 5, the exemplary data collection process 500 extracts relationship information during step 520, which in turn is stored within a relational database during step 530. A tag, pointer, or flag may be associated with the formatted data during step 540 indicating where the raw data corresponding to the formatted data is located. Thereafter, when a request for raw data is received, the software engine may be

directed to the appropriate raw data, in which case the translators within the software engine will translate and format the data as needed.

In addition, the formatted data can optionally be annotated during step 550 with identifiers on which the data may be retrieved. For example, search tags or Meta tags can be added to the formatted data to facilitate the search process. In this manner, the data can be searched for data associated with a particular item. In addition, one or more software processes load the formatted data into a server within the network interface card 230 or a remote server.

Finally, reports can be generated during step 560 that are visualized to the end user. As discussed hereinafter, exemplary reports may be based on the lot level, the product level, the tool level, or any other sorting criteria that the users may desire, such as time-based intervals.

FIG. 6 is a flow chart describing an exemplary implementation of the preventative maintenance learning process 600 incorporating features of the present invention. As previously indicated, the data that is collected from equipment in a semiconductor factory is analyzed by the preventative maintenance learning process 600 following a failure using pattern recognition techniques to identify patterns in the data that suggested a failure was about to occur in order to prevent future imminent failures.

As shown in FIG. 6, the preventative maintenance learning process 600 is initiated during step 610 upon the detection of a failure of a process tool 210. The data associated with the process tool 210 in the time frame of a number of similar detected failures is retrieved during step 620. Pattern recognition techniques, such as neural networks, are applied to the data set during step 630 to identify patterns in the data that suggested a failure was about to occur.

One or more rules are generated during step 640 that define the identified pattern in terms of one or more predefined data characteristics. Thereafter, real-time data is monitored during step 650 to detect the predefined data characteristic(s) and thereby indicate when a failure is about to occur during step 660.

For example, a pressure drop across gas inlets to the abatement equipment (a common failure mode) can be monitored. A trigger point could be established by a skilled engineer that would alert of a pending problem early enough to schedule a preventative maintenance visit. In a further variation, all sensor data for an entire

sequence of operation during normal operation can be bench marked. Any deviation would alert a field service engineer of a pending problem. A further automation method of this technique is to tie the sensor data into a neural network. When a failure is detected, the system could scan back through the records looking for a leading indicator for future predictions.

A predictive datalogging device (the predictor generating device) can communicate with a tool, such as a Vector water scrubber, using the network interface card 230 associated with the lower level tool. In the present example, an algorithm generating device (AGD) logs the inlet pressure of the lower level tool. A pressure transducer produces a signal that measures the pressure drop across the inlet. The AGD logs the pressure and the equipment fault that is generated when the lower level tool senses too high an inlet pressure (if the predictive algorithm in the lower level tool was in error). The AGD now knows that as the inlet pressure approaches a trip point the AGD should warn of the imminent pressure failure. This fitted curve and the warn point can be downloaded to the lower level tool for local prediction. The fitting curve and warning point can be uploaded to a server further up the network. This server/AGD can load the fitting curve into its database. A statistically more robust algorithm can be generated and downloaded or distributed to the fleet of predictive lower level tools.

In another example, CuChem and Solderchem electrochemical depostion (ECD) bath analysis tools measure both the inorganic and organic constituents present in the ECD plating solutions. The analysis tools calculate the concentrations of the various constituents and feed this data to a chemical management tool. The chemical management tool replenishes the bath with the appropriate additive to ensure that the bath is always running at the intended target concentrations to enhance wafer yields. In the event that a system malfunction occurs in the chemical management tool or plating bath, so that the target concentrations are not maintained as determined by the Cu- or SolderChem analyzers, e-diagnostics play a crucial role. Thus, the present invention can perform a predictive analysis on the plating bath in addition to predictive function on how it is operating.

The analyzer can trigger the plating bath tool, chemical management system, and the analyzer itself to perform self-diagnostic checks and relay the answer to the central e-diagnostic module. The e-diagnostic tool can alert the central monitoring and

control center 400 and a process engineer directly, for example, by e-mail, cell phone or pager (or a combination of the foregoing). This may potentially shorten the time between getting appropriate people to the site in the a timely manner, getting appropriate parts to the site sooner, or allowing potential problems to worked around before they become critical. All of the above would reduce downtime for a process.

FIG. 7 is a schematic block diagram of an exemplary air composition monitor 700 incorporating features of the present invention. The exemplary air composition monitor 700 shown in FIG. 7 monitors the air quality in a semiconductor factory 200 for a broad range of chemicals, for example, that may be harmful to humans. Each gas is specifically identified by a spectral fingerprint. The air composition monitor 700 helps to identify dangerous conditions and can identify unknown odors. The air composition monitor 700 may be embodied as the ATMI ACM, commercially available from ATMI, Inc. of San Jose, CA, as modified herein to provide the features and functions of the present invention.

The exemplary air composition monitor 700 employs a fourier transform infrared (FT-IR) analyzer 710 to monitor a number of gases. The air composition monitor 700 collects air samples from a number of air hoses 720-1 through 720-N that may be distributed throughout a semiconductor factory 200. Generally, an interferometer in the air composition monitor 700 modulates a beam of infrared light and sends the modulated light through a gas cell containing the air sample, where airborne chemicals in the sample absorb infrared light. The remaining light is reflected to a detector where the infrared light intensity is digitized, then computed to an error-free infrared spectrum containing all of the analytical information. The air composition monitor 700 examines the infrared spectrum to identify and quantify each chemical present in the air samples. One or more thresholds are established for each monitored gas, and the air composition monitor 700 can be configured to take appropriate steps when a given threshold is exceeded, such as generating an alarm or notifying the appropriate personnel, using one or more alarm or notification functions, in a known manner.

The present invention enables the remote configuration operation and monitoring of the air composition monitor 700 in a semiconductor factory, as well as the collection and storage of data from the air composition monitor 700 in real time. According to one aspect of the invention, the air composition monitor 700 can

accommodate the monitoring of new tools or new chemicals in the semiconductor factory 200. Specifically, new equipment 310 can be deployed with the functionality of a network interface card 230 built right in, and legacy and third party equipment 320, 300 can be retrofitted by providing an associated network interface card 230 to perform the data collection and translation functions.

In addition, the maintenance of the air composition monitor 700 can be improved by the preventative maintenance learning process 600, shown in FIG. 6. For example, each of the air hoses 720 include a filter to prevent contaminants from entering the air composition monitor 700 itself. Over time, the filters can gradually develop a build up of contaminants that diminish the efficiency of the filter. The failure would be manifested by a degradation in the pressure that is attainable within a given tube 720 over time. By performing a data mining and pattern recognition process in accordance with the preventative maintenance learning process 600, thresholds can be established on the tube pressure data that indicate when a preventative maintenance task should be performed on the filter. In this manner, when the pressure in the tube falls below the threshold, a preventative maintenance task can be automatically scheduled to clean or replace the filter.

Data Collection and Reporting

In this manner, the data collection process 500 provides a relationship between raw data that is either stored within external data collection facilities or internal data management systems in a system of templates coupled to data analysis tools that allow a user to generate consistent and customized reports on this data. The present invention can either analyze data on demand or data that has been stored. For example, the present invention may record a pointer to raw data that is maintained in an external data collection facility. When the software engine of the present invention receives a request for the data, it will then extract that data from the external data collection facility and generate the user-specified report based on internal templates and analysis tools. Furthermore, some reports required on a daily basis may be automatically generated based on data that is automatically collected, analyzed and visualized based on a set of rules provided by or stored within the software engine of the present invention. This eliminates the need for individuals to manually access individual files for yield status and potentially manually verify the conditions of various tools and report these or consolidate these into a user generated report.

The user interface may launch a separate web browser window to display reports when the user selects a report to be generated. This separate window is called the report window. The data selector screen passes the user's data selection and report information to another Common Gateway Interface (CGI) program, then the data selector screen communicates with the report window using a language, such as JavaScript. The CGI program first verifies the user data selection and report selection and then generates a report by running the appropriate report template. Report templates may be, for example, PERL programs that contain all the logic for generating a report given the data object oriented interface. In addition, the present invention provides some graphical objects to the report templates that enable them to generate graphs, wafer maps, charts, or other visualizations of the data, as known to those skilled in the art. In one embodiment, the output of the report template is an HTML web page that is then displayed in the reports window. For example, one can write a report template that runs a shell script. The HTML web pages can include XML, GIF/JPEG images, Java applets, or VBSCRIPT applets.

Typical standard reports in the semiconductor fabrication industry include materials consumption, waste production, yield parameter trends by equipment, standard yield parameter trends, equipment utilization reports, equipment status reports, probe card analysis, equipment tracking, equipment commonality and wafer maps. The present invention serves as a data management tool accessible via a web browser using common analysis tools that are accessed via an application server. Additionally, translators may import data from additional tools.

Templates provide the ability for users to customize generated data reports. For example, corporate logos may be incorporated onto the reports or proprietary data markings, thus ensuring that a standard for the reports as identification of proprietary data or potential trade secret data can be put in place.

In a semiconductor application, users first select lots and wafers of interest and pick a report that is then displayed in a separate web browser window. A CGI program generates the data selector screen. This program serves to interface to an index database (not shown), containing a list of all lots and wafers managed by the central monitoring and control center 400. When the user interacts with the data selector screen, the user is interfacing with CGI program and navigating the index database to select the lots and wafers of interest.

The data selector screen launches a separate web browser window to display reports when the user selects a report to be generated. This separate window is called the report window. The data selector screen passes the user's data selection and report information to a CGI program, then the data selector screen communicates with the report window using a language such as JavaScript. A CGI program first verifies the user data selection and report selection and then generates a report by running the appropriate report template. In addition, graphical objects can be provided to the report templates that enable them to generate graphs, wafer maps, charts, or other visualizations of the data, as known to those skilled in the art.

The present invention may be integrated with existing infrastructure and databases. For example, manufacturing facilities typically have large databases with yield and process data. Therefore, the historical data, to a limited extent, is already available. Raw data files may be accessed even when contained within external databases. For example, if one was manufacturing semiconductor devices and needed to look at the contact resistance, one may also be able to look at the metrology sheet resistances associated with specific lots for a specific period of time or similarly extract photo information about the critical dimensions associated with the various metal layers. This is an example of three different pieces of information, namely, sheet resistance, contact resistivity, and photo critical dimensions, that are typically stored in three different places.

The information architecture of the present invention can be applied to existing data storage systems. The network interface cards 230 of the present invention can be coupled to databases or other like memory storage locations. In this embodiment, the network interface cards 230 read the raw data to create a set of summary files that are stored within a relational database. The advantage provided here is the ability to navigate and locate requested data within the database(s) quickly and raw data is accessible from the data collection sites via network interface cards 230 that extract and format data for the user. Thus, the user can navigate and access data via a network based user interface as one would navigate information on the Interact. Relational databases prevent the management of the information from becoming extremely large and un-navigable, by maintaining data summaries or other like markers within a relational database, raw data can be quickly accessed. Additionally, this raw data may be stored as flat files, ASCII files or some other

format files within a conventional file storage system outside of a database, where only the location and relationship of that data is maintained within the relational database.

Therefore, if one wanted to correlate the lots that had a product yield of, e.g., less than 40%, and were processed on a particular etcher or etchers fed from particular ancillary equipment devices, one could simply input that inquiry via a user interface and a software engine would access the relational database to determine those files. After those data files had been identified, one could access additional databases or directory structures to access the raw data, which would then be integrated and visualized to the end user at user interface.

The present invention provides an important advantage over prior art systems in that code within the network interface card 230 or optional server 240 serves to collect the raw data from programmable logic controllers 220 while maintaining relationships with the raw data. The present invention provides a portal that allows raw data from many diverse equipment systems to be integrated within one consolidated view. This can be extended beyond a single factory to many diverse applications, such as in the semiconductor industry where individual processes are outsourced to foundry or specialty operations, or where geographically diverse operations are used in the processing of a single product. Therefore, traditionally, when a product is outsourced for an individual operation, when it is returned to the processing facility, a hard table or printout of the data associated with that operation is returned with the product. Similarly, a semiconductor device completed at the fabrication facility may be shipped to an assembly facility where it is actually bonded to external wires and packaged. It would be desirable to seamlessly integrate this data with the data from the processing facility to have a better understanding of failures mechanisms within the device.

With the web-based application or user interface of the present invention, access to and control of a variety of diverse equipment systems is obtained via network connections. Processing may be either centralized at a network server or distributed to individual network interface cards 230 dependent on usage or function. When a centralized server processes data, processing requirements at the local level are minimized. As long as the various equipment systems are capable of establishing a network connection, then the centralized server may process the data. Additionally, this

architecture minimizes the system requirements for the user interface increasing the potential platforms on which the user interface may be executed.

The present invention may utilize data collection systems comprising databases or data loading systems wherein a software engine can detect automatically when new data has arrived and pull this data into the system. The configuration of the data collection source may determine whether or not this data is then in turn stored within another database or data file structure. Whether or not the raw data is maintained within the data collection system or needs to be maintained in a data storage facility accessible to software engine is a function of configuration.

Once a software engine is connected to a data source, the software engine can monitor the data source. If the data source is a database, the database is polled for data on a recurring basis. If the database is a file created by measurement equipment, then the software engine monitors and sets up directories for those type files and automatically loads this in. Since the software engine is network or web based, it is completely platform independent, and merely requires that user interface is operable on the platform that a user is using. Therefore, one would be able to access data with appropriate permissions from any place in the world. This is particularly valuable for disperse manufacturing systems where semiconductors may be produced at a foundry in a country such as Taiwan and assembled in Hong Kong for products that are ultimately assembled in the United States or where the engineers overseeing the process are located in a remote facility.

Automated Supply System

The present invention can be configured to automatically order materials or initiate preventative maintenance tasks, or automatically notify customers of the need to order such materials or initiate such preventative maintenance tasks. More specifically, the integrated equipment: monitoring system of the present invention provides an automated supply system that monitors raw material inventories and can automatically initiate orders for new raw materials as existing materials are consumed. In this way, the manufacturing facility can achieve a Just-In-Time inventory management system for all consumable materials within the facility. Thus, on hand inventory costs are reduced and the potential for aged raw materials is reduced.

The present invention allows the semiconductor factory 200 to optimize their chosen supply inventory. By tracking integrated data sets, one can accurately predict

the demand for any given raw material and thus optimize the inventory contained not only in the equipment system for individual manufacturing facilities but within the production facility servicing a set of manufacturing facilities. This allows a production facility to reduce its size and overhead by incorporating just-in-time inventory controls internally.

Modularity and Scalability

Modularity provided by the present invention comes in two levels. The present invention is capable of integrating diverse data sources and that one is not locked in to the type of data sources from day one. Modularity is in two levels. First, one can create custom modules or customize off-the-shelf modules in the sense that one can add different kinds of data one at a time, not necessarily all at once. For example, if there is a new foundry partner or a new assembly house, it is possible to plug and play that type of data, as a data collection source, into a software engine. Furthermore, the users at the data collection source, with the right permissions, will have the same access as any other user so long as that user is capable of displaying via network connection user interface. In addition, additional process tools 210 are easily monitored by the present invention as they are added to a semiconductor factory 200, thus providing a scaleable solution.

It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention.

We claim:

1. A method for remotely monitoring at least one equipment device in a semiconductor factory, said method comprising:

providing an interface to said equipment device having at least two communication ports, said interface being addressable over a network and translating data from said equipment device into a desired uniform format; and

collecting data from said equipment device using said interface.

2. The method of claim 1, wherein said at least one equipment device is an ancillary device associated with a process tool.

3. The method of claim 1, wherein said network addressable interface allows said at least one equipment device to be accessed by a remote user.

4. The method of claim 1, wherein said network addressable interface operates as a host site.

5. The method of claim 1, wherein said network addressable interface allows data to be obtained regarding the operation of said at least one equipment device.

6. The method of claim 1, wherein said data from said equipment device is translated from a format associated with a third party vendor into a desired uniform format.

7. The method of claim 1, wherein said data from said equipment device is translated from a format associated with one of a plurality of third party vendors into a desired uniform format.

8. The method of claim 1, wherein said data from said equipment device is monitored in real time to determine when a material needs to be replaced.

9. The method of claim 1, wherein said data in said desired uniform format maintains a relationship with corresponding raw data to permit integration of data from an outsourcing vendor.

10. The method of claim 1, wherein said data from said equipment device is monitored in real time to automatically adjust one or more process parameters in said semiconductor factory.

11. The method of claim 1, wherein said data from said equipment device is monitored in real time to automatically initiate the activation of one or more abatement devices.

12. The method of claim 1, wherein data from a plurality of equipment devices associated with a process tool is monitored and evaluated to provide an indication that said plurality of associated equipment devices are operating within a predefined threshold.

13. The method of claim 1, wherein said data from said equipment device is monitored in real time to automatically detect completion of a task in said semiconductor factory.

14. The method of claim 1, wherein data from a plurality of equipment devices associated with a process tool are packaged as a tool skid and monitored to provide an indication that said packaged plurality of associated equipment devices are operating within a predefined threshold.

15. A method for remotely monitoring at least one equipment device in a semiconductor factory, said method comprising:

collecting historical data regarding the operation of said equipment device;

detecting at least one failure of said equipment device;

analyzing said historical data using a pattern recognition technique to identify at least on pattern in said historical data that suggested a failure was about to occur;

defining a rule that characterizes said identified pattern; and

observing real-time data regarding the operation of said tool to determine if said rule is satisfied.

16. The method of claim 15, wherein said pattern recognition technique further comprises the steps of applying a neural network to said historical data.

17. The method of claim 15, wherein said pattern recognition technique further comprises the steps of manually analyzing said historical data.

18. The method of claim 15, wherein said rule indicates a corresponding preventative maintenance task that should be performed when said rule is satisfied.

19. The method of claim 15, wherein said pattern recognition technique identifies one or more thresholds that suggest a failure is about to occur.

20. The method of claim 15, wherein said at least one equipment device is an ancillary device associated with a process tool.

21. The method of claim 15, wherein said collecting step is performed using an interface to said equipment device having at least two communication ports, said interface being addressable over a network and translating data from said equipment device into a desired uniform format.

22. A method for analyzing a failure in a semiconductor factory, said method comprising:

collecting historical data regarding the operation of a plurality of interrelated equipment devices that operate in said semiconductor factory;

detecting at least one failure in said semiconductor factory; and

analyzing said historical data for each of said plurality of interrelated equipment devices to identify a root cause event that led to said detected failure.

23. The method of claim 22, wherein said collecting step is performed using an interface to said ancillary equipment devices, said interface being addressable over a network and translating data from said ancillary equipment device into a desired uniform format.

24. A system for remotely monitoring at least one equipment device in a semiconductor factory, said system comprising:

a memory that stores computer-readable code; and

a processor operatively coupled to said memory, said processor configured to implement said computer-readable code, said computer-readable code configured to:

provide an interface to said equipment device having at least two communication ports, said interface being addressable over a network and translating data from said equipment device into a desired uniform format; and

collect data from said equipment device using said interface.

25. The system of claim 24, wherein said at least one equipment device is an ancillary device associated with a process tool.

26. The system of claim 24, wherein said network addressable interface allows said at least one equipment device to be accessed by a remote user.

27. The system of claim 24, wherein said network addressable interface operates as a host site.

28. The system of claim 24, wherein said network addressable interface allows data to be obtained regarding the operation of said at least one equipment device.

29. The system of claim 24, wherein said data from said equipment device is translated from a format associated with a third party vendor into a desired uniform format.

30. The system of claim 24, wherein said data from said equipment device is translated from a format associated with one of a plurality of third party vendors into a desired uniform format.

31. The system of claim 24, wherein said data from said equipment device is monitored in real time to determine when a material needs to be replaced.

32. The system of claim 24, wherein said data in said desired uniform format maintains a relationship with corresponding raw data to permit integration of data from an outsourcing vendor.

33. The system of claim 24, wherein said data from said equipment device is monitored in real time to automatically adjust one or more process parameters in said semiconductor factory.

34. The system of claim 24, wherein said data from said equipment device is monitored in real time to automatically initiate the activation of one or more abatement devices.

35. The system of claim 24, wherein data from a plurality of equipment devices associated with a process tool is monitored and evaluated to provide an indication that said plurality of associated equipment devices are operating within a predefined threshold.

36. The system of claim 24, wherein said data from said equipment device is monitored in real time to automatically detect completion of a task in said semiconductor factory.

37. The system of claim 24, wherein data from a plurality of equipment devices associated with a process tool are packaged as a tool skid and monitored to provide an indication that said packaged plurality of associated equipment devices are operating within a predefined threshold.

38. A system for remotely monitoring at least one equipment device in a semiconductor factory, said system comprising:

a memory that stores computer-readable code; and

a processor operatively coupled to said memory, said processor configured to implement said computer-readable code, said computer-readable code configured to:

collect historical data regarding the operation of said equipment device;

detect at least one failure of said equipment device;

analyze said historical data using a pattern recognition technique to identify at least on pattern in said historical data that suggested a failure was about to occur;

define a rule that characterizes said identified pattern; and

observe real-time data regarding the operation of said tool to determine if said rule is satisfied.

39. The system of claim 38, wherein said wherein said processor is further configured to apply a neural network to said historical data.

40. The system of claim 38, wherein said wherein said processor is further configured to facilitate a manual analysis of said historical data.

41. The system of claim 38, wherein said rule indicates a corresponding preventative maintenance task that should be performed when said rule is satisfied.

42. The system of claim 38, wherein said pattern recognition technique identifies one or more thresholds that suggest a failure is about to occur.

43. The system of claim 38, wherein said at least one equipment device is an ancillary device associated with a process tool.

44. The system of claim 38, wherein said historical data collection is performed using an interface to said equipment device having at least two communication ports, said interface being addressable over a network and translating data from said equipment device into a desired uniform format.

45. A system for analyzing a failure in a semiconductor factory, said system comprising:

a memory that stores computer-readable code; and

a processor operatively coupled to said memory, said processor configured to implement said computer-readable code, said computer-readable code configured to:

collect historical data regarding the operation of a plurality of interrelated equipment devices that operate in said semiconductor factory;

detect at least one failure in said semiconductor factory; and

analyze said historical data for each of said plurality of interrelated equipment devices to identify a root cause event that led to said detected failure.

46. The system of claim 45, wherein said historical data collection is performed using an interface to said ancillary equipment devices, said interface being addressable over a network and translating data from said ancillary equipment device into a desired uniform format.

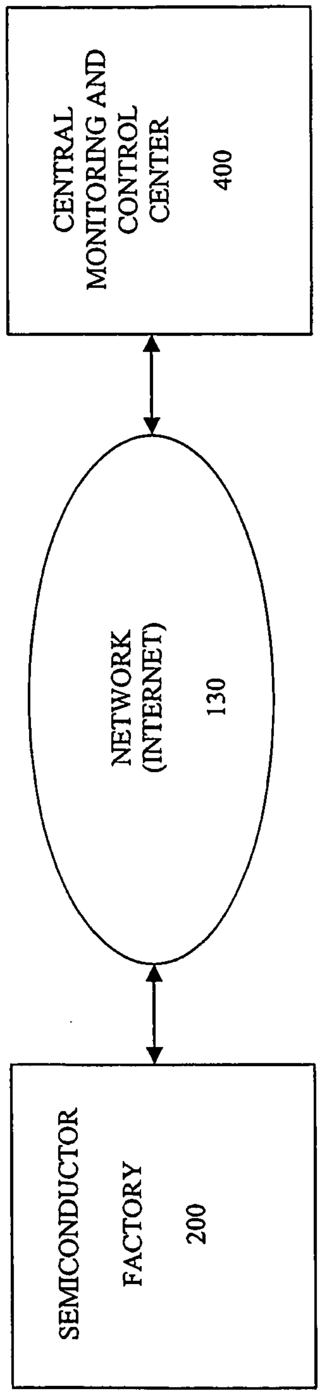

CENTRAL MONITORING AND CONTROL CENTER
400
NETWORK (INTERNET)
130
SEMICONDUCTOR FACTORY
200

FIG. 1

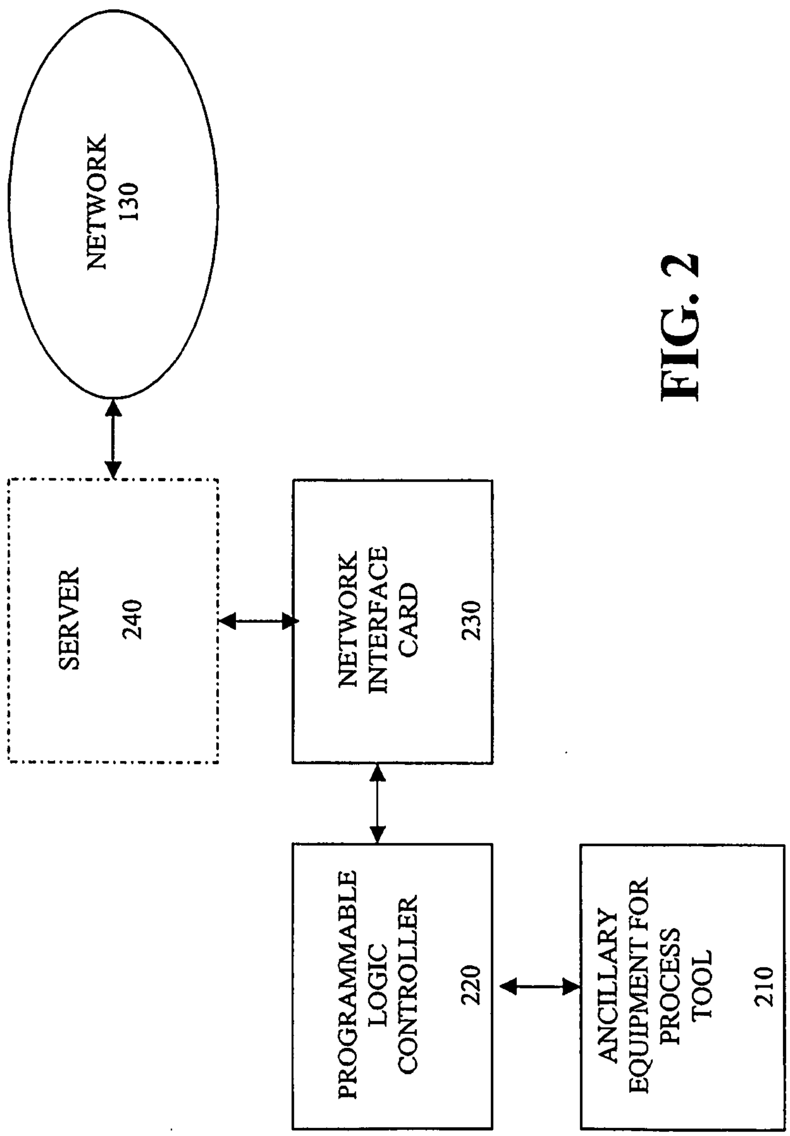
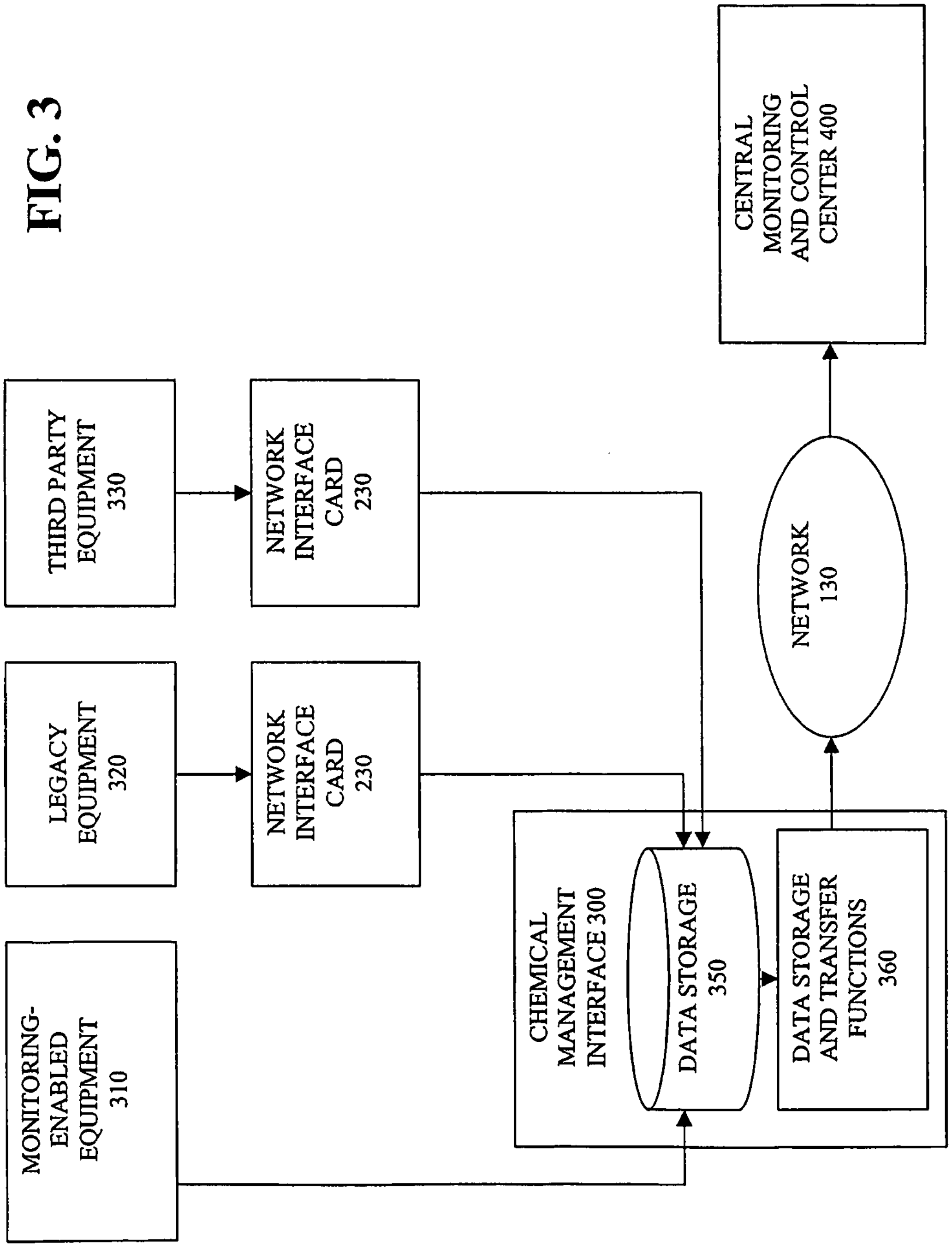

NETWORK
130
SERVER
240
NETWORK
INTERFACE
CARD
230
PROGRAMMABLE
LOGIC
CONTROLLER
220
ANCILLARY
EQUIPMENT FOR
PROCESS
TOOL
210

FIG. 2

FIG. 3


THIRD PARTY EQUIPMENT 330
LEGACY EQUIPMENT 320
MONITORING-ENABLED EQUIPMENT 310
NETWORK INTERFACE CARD 230
NETWORK INTERFACE CARD 230
CHEMICAL MANAGEMENT INTERFACE 300
DATA STORAGE 350
DATA STORAGE AND TRANSFER FUNCTIONS 360
NETWORK 130
CENTRAL MONITORING AND CONTROL CENTER 400

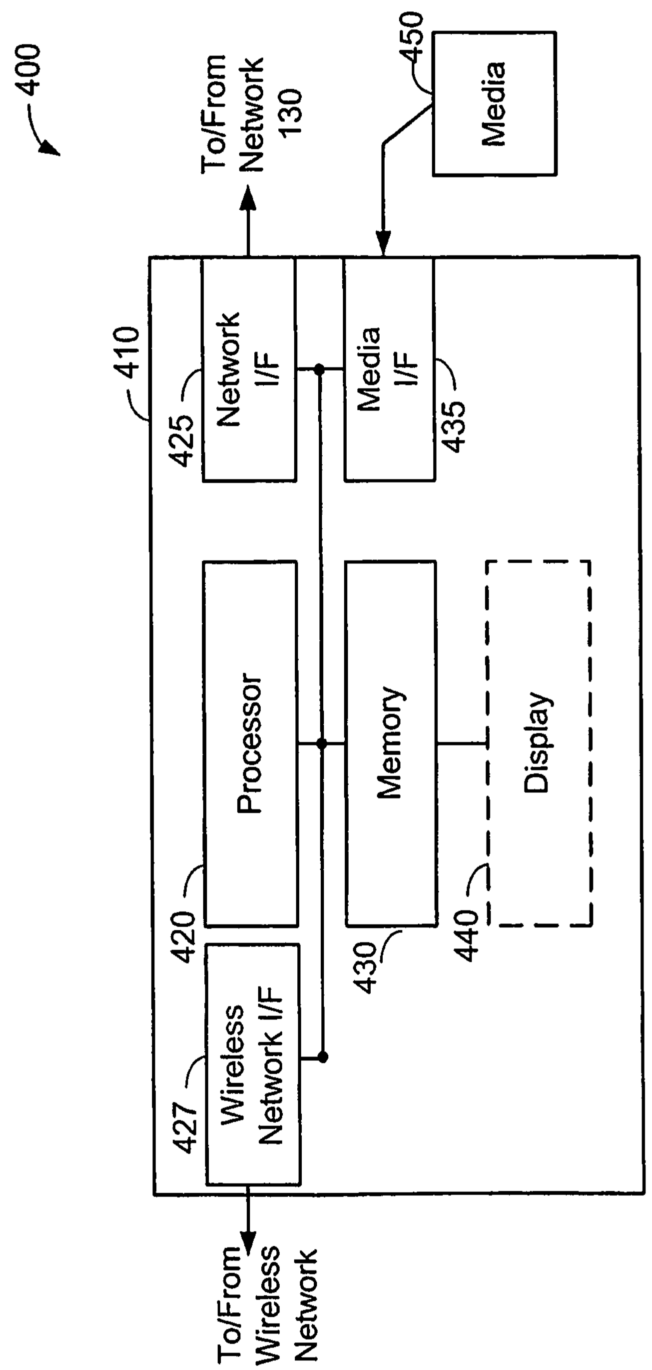

400
410
To/From
Network
130
450
Media
425
Network
I/F
Media
I/F
435
420
Processor
Memory
430
Display
440
427
Wireless
Network I/F
To/From
Wireless
Network

FIG. 4

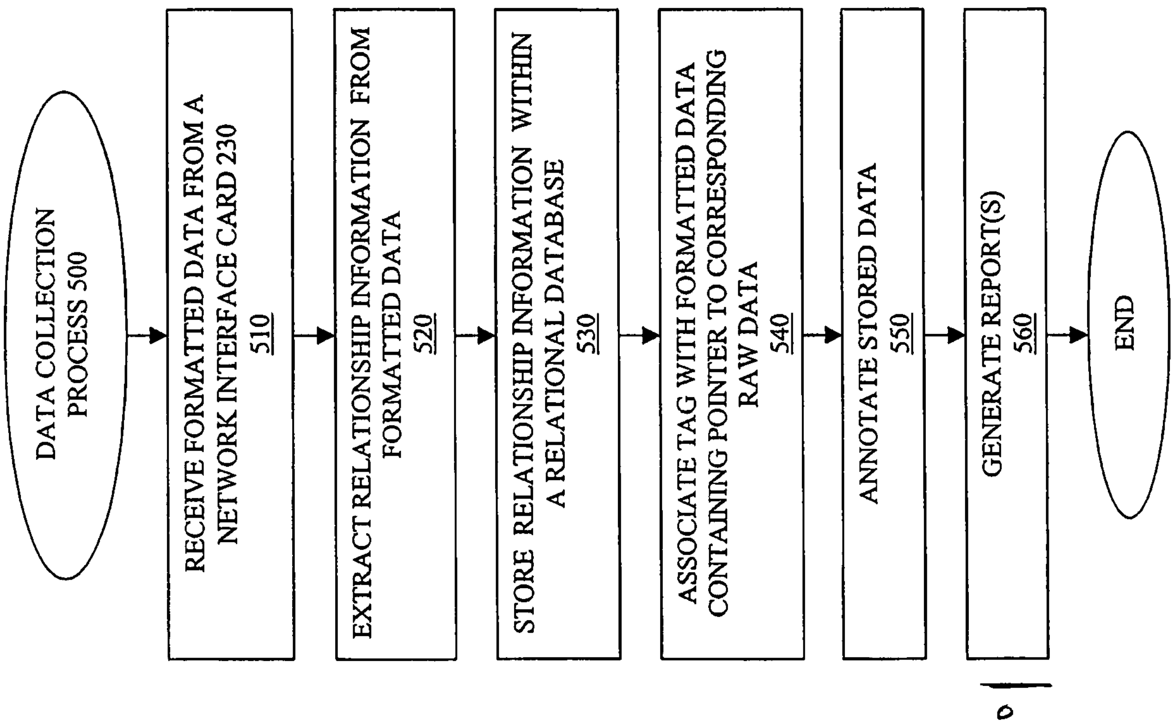

DATA COLLECTION PROCESS 500
RECEIVE FORMATTED DATA FROM A NETWORK INTERFACE CARD 230 510
EXTRACT RELATIONSHIP INFORMATION FROM FORMATTED DATA 520
STORE RELATIONSHIP INFORMATION WITHIN A RELATIONAL DATABASE 530
ASSOCIATE TAG WITH FORMATTED DATA CONTAINING POINTER TO CORRESPONDING RAW DATA 540
ANNOTATE STORED DATA 550
GENERATE REPORT(S) 560
END

FIG. 5

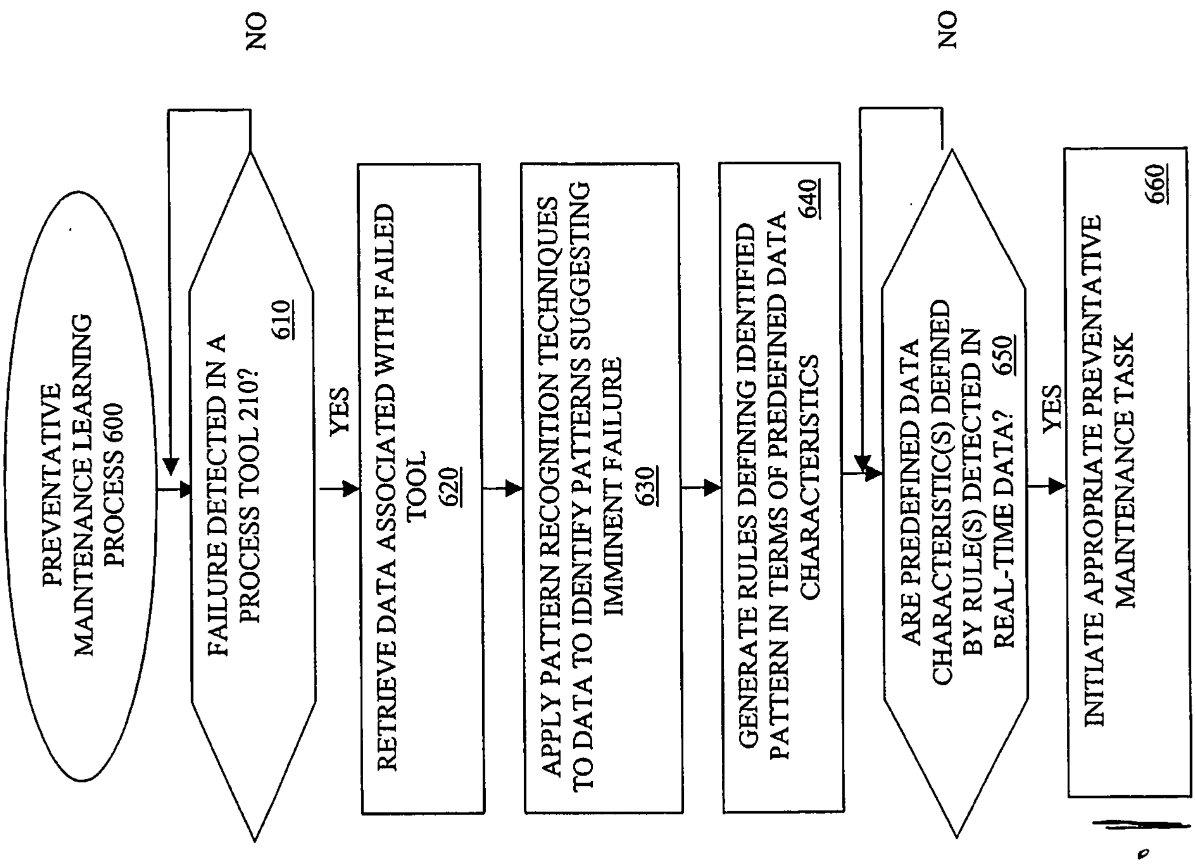

PREVENTATIVE MAINTENANCE LEARNING PROCESS 600
FAILURE DETECTED IN A PROCESS TOOL 210? 610
NO
YES
RETRIEVE DATA ASSOCIATED WITH FAILED TOOL 620
APPLY PATTERN RECOGNITION TECHNIQUES TO DATA TO IDENTIFY PATTERNS SUGGESTING IMMINENT FAILURE 630
GENERATE RULES DEFINING IDENTIFIED PATTERN IN TERMS OF PREDEFINED DATA CHARACTERISTICS 640
ARE PREDEFINED DATA CHARACTERISTIC(S) DEFINED BY RULE(S) DETECTED IN REAL-TIME DATA? 650
NO
YES
INITIATE APPROPRIATE PREVENTATIVE MAINTENANCE TASK 660

FIG. 6

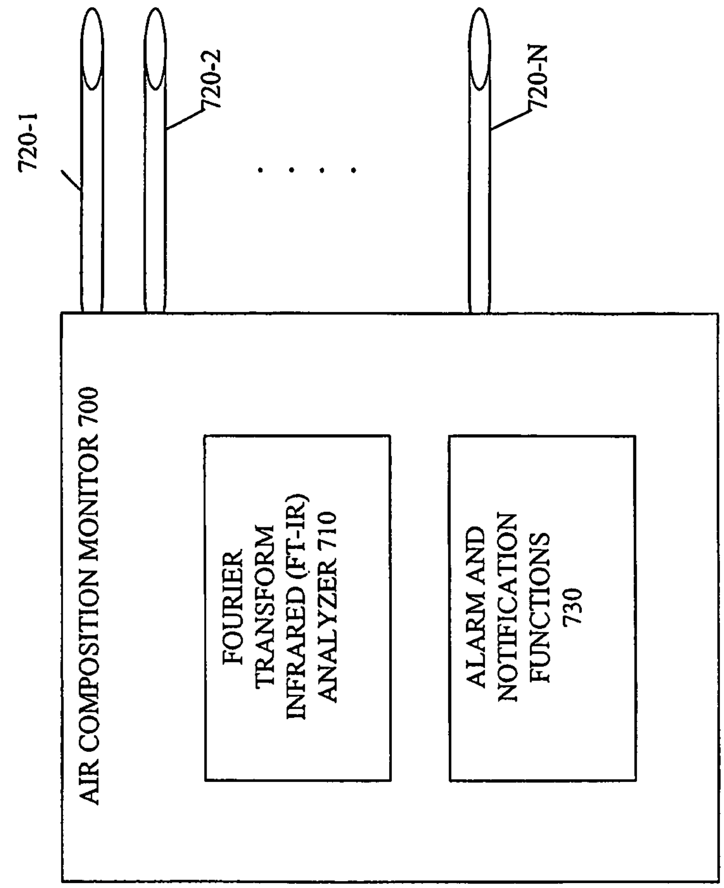

720-1
720-2
720-N
AIR COMPOSITION MONITOR 700
FOURIER TRANSFORM INFRARED (FT-IR) ANALYZER 710
ALARM AND NOTIFICATION FUNCTIONS 730

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/036499

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 02/054223 A (ZERO MAINTENANCE INTERNATIONAL CORPORATION) 11 July 2002 (2002-07-11) page 2, line 8 - page 5, line 23 page 7, line 3 - line 23	2,4,6,7, 12,14, 17,18, 20,22, 26,29
Y	US 6 442 639 B1 (MCELHATTAN KENT D ET AL) 27 August 2002 (2002-08-27) abstract column 10, line 11 - line 50	5,11,21